PRINCIPLES OF THE MECHANISM OF A SCIENTIFIC INSTRUMENT FOR STUDYING HIGH-ENERGY COSMIC RAYS ON THE SPACE STATION "Proton-4"

V. V. Bugakov, S. A.Belyakov, N. L. Grigorov, Yu. V. Gubin
L. F. Kalipkin, G. P. Kakhidze, I. D. Rapoport,
I. A. Savenko, A. V. Smirnov, V. Ya. Shiryayeva,
P. P. Shishkov, V. F. Shesterikov, B. M. Yakovlev
and Yu. V. Trigubov

Translation of: "Printsipy ustroystva na nauchnoy apparatury dlya izucheniya kosmicheskikh luchey vysokoy energii na kosmicheskoy stantsii 'Proton-4'". Izvestiya Akademii Nauk SSSR, Seriya Fizicheskaya, Academy of Sciences USSR, Vol. 34, No. 9, 1970, pp. 1818-1828.

N71-20576
(ACCESSION NUMBER)
27
(PAGES)
(NASA CR OR TMX OR AD NUMBER)
(THRU)
03
(CODE)
29
(CATEGORY)
FACILITY FORM 602

APR 1971
RECEIVED
NASA STI FACILITY
INPUT BRANCH

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546 MARCH 1971

PRINCIPLES OF THE MECHANISM OF A SCIENTIFIC INSTRUMENT FOR STUDYING HIGH-ENERGY COSMIC RAYS ON THE SPACE STATION "Proton-4"

V. V. Bugakov, S. A. Belyakov, N. L. Grigorov, Yu. V. Gubin
L. F. Kalishkin, G. P. Kakhidze, I. D. Rapoport,
I. A. Savenko, A. V. Smirnov, V. Ya. Shiryayeva,
P. P. Shishkov, V. F. Shesterikov, B. M. Yakovlev
and Yu. V. Trigubov

ABSTRACT. This article discusses the flux of high- and ultrahigh-energy particles in outer space. Instruments are described for measuring nuclear-proton interactions and for detecting quarks in primary cosmic radiation. A description is given of the ionization calorimeter, the charge and radiation detectors and the targets, as well as of the operating principles of the ionization calorimeter IC-15. Finally, the structural characteristics of the IC-15 are given to include the ionization chambers, proportional counters, detector units, targets and filters. The article is accompanied by drawings depicting these instruments and graphs of their characteristics.

The study of the flux of high- and ultrahigh-energy particles in outer /1818
space, clarification of their composition, energy spectrum and characteristics of interaction with matter is one of the real problems in the physics of cosmic rays. The planned development of investigations in this direction permits obtaining experimental data necessary for solving the problem of the origin of high-energy cosmic radiation and explaining the processes of its propagation in the Galaxy. Along with this, these same investigations are of great interest for studying the general properties of elementary particles revealed in the processes of high-energy interaction.

*Numbers in the margin indicate pagination in the original foreign text.

The first experiments on direct research of high-energy particles of primary cosmic radiation were made on the scientific stations "Proton-1", "Proton-2" and "Proton-3". Scientific equipment was installed on these stations for measuring the overall energy spectrum of cosmic radiation up to 10^{14} eV and the energy spectrum of protons up to 10^{13} eV [1 - 3]; this equipment was also used to measure the effective inelastic nuclear interaction cross section of high-energy protons with light nuclei of carbon and hydrogen [1 - 3] and to study high-energy electrons in circumterrestrial space [1, 2, 4]; it also sought quarks in the primary cosmic rays [5] and was used for studying the chemical composition of cosmic rays in the region of "low" energies $\sim 10^9$ eV/nucleon [6] and registering high-energy gamma-quanta in the composition of primary cosmic radiation [7].

Based on the data obtained in these experiments, the spectrum of the protons in the energy range $\geq 10^{12}$ eV was found to differ from the spectrum of the heavier nuclei; with increase in energy of the particles the cosmic rays are "enriched" by heavier nuclei [8 - 14]. Also detected was an increase in the effective cross section of the inelastic interaction between the protons and the light nuclei by $\sim 20\%$ with growth in proton energy from 20 to 600 GeV [9, 11, 15 - 20]. The equipment registered relatively intense currents of electrons of secondary origin having energies of $\sim 10^2$ MeV in circumterrestrial space [21].

In view of the importance of these results for aspects of astrophysics and nuclear physics in studying cosmic rays, it was necessary to continue these investigations using equipment which permitted measuring the energy of the primary particles and their electric charge with a high degree of accuracy. This equipment also permitted repeating the measurements of the effective cross section of inelastic interaction between the high-energy protons and the atomic nuclei using equipment that differed from that previously used. It was also possible to study the form of the spectrum of the primary particles by direct methods in the energy range up to 10^{15} eV, as well as to obtain information on the characteristics of the interaction of complex nuclei of

high- and ultrahigh-energy cosmic rays with matter.

To solve these problems we developed and manufactured new equipment (the IC-15 instrument), which differs substantially from the SEZ-14 equipment [3], used on the space stations "Proton-1, 2, 3". This equipment, weighing more than 12 T, was installed on the scientific space station "Proton-4", launched November 16, 1968.

To continue the investigations of high-energy electrons in circumterrestrial space and to search for quarks in primary cosmic rays, first, modernized SEZ-12 instruments for registering high-energy electrons [1, 2, 21] and, secondly, a SEZ-13 to search for quarks [5, 22] were installed on board the "Proton-4". Modernization of these instruments included deriving additional information on the operation of the radiation counters (SEZ-12) and certain technical improvements (SEZ-13). Since these instruments basically retained their previous principles in registering particles, dimensions and logic of operation, for lack of space here we shall not describe the variations introduced into them. /1819

Below we give a description of the spectrometer for high and ultrahigh energy particles — the IC-15, installed on the scientific station "Proton-4".

I. Main Circuit of the IC-15 Spectrometer

The instrument consists of the following basic main elements (Figure 1):

1. An Ionization Calorimeter for determining the energy of the particles, which includes filter layers of lead (layer 4 in the upper part of Figure 1) and iron (the next 13 layers), 16 ionization chambers between the layers (IC_1 - IC_{16}) for measuring ionization. The IC-15 ionization calorimeter differs from a similar device used on the previous "Proton" stations by a greater cross section and considerably larger amount of filter material, thus permitting the range to be widened and the accuracy of the energy measurements

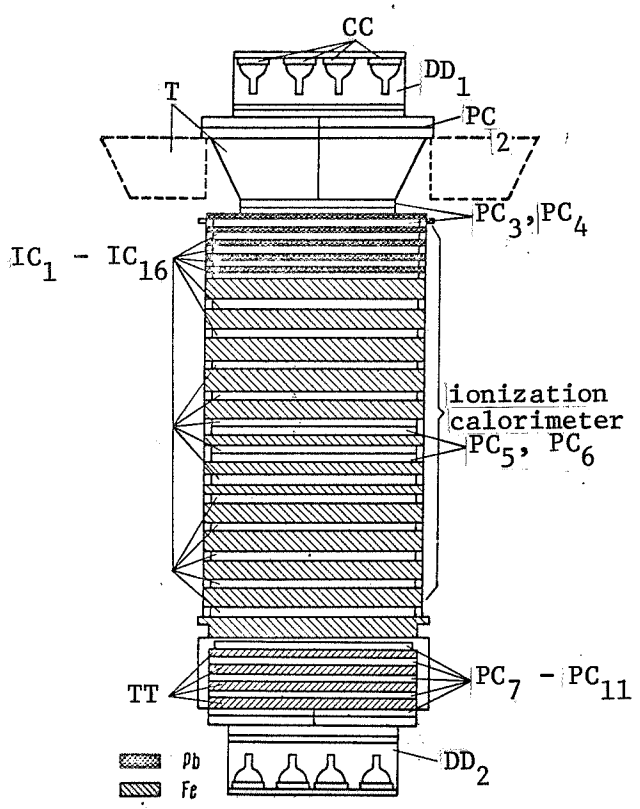

Figure 1. Basic schematic of the IC-15 spectrometer for studying high-energy particles of cosmic rays: T are the interchangeable graphite and polyethylene targets; CC are the Cerenkov counters; TT are thin targets of graphite; DD are the detectors of charge and direction of the particles; IC are the ionization chambers; PC are the proportional counters.

to be increased. Furthermore, the introduction of a large number of individual detectors between the layers makes it possible to study the processes of particle absorption of different types in the material of the calorimeter.

2. Charge Detectors of the Registered Particles were placed on two opposite sides of the ionization calorimeter; on the side of the "upper" (DD_1) and "lower" (DD_2) input windows. Each of the charge detectors DD is composed of 16 thin Cerenkov counters, the total effective area of which is about 300 cm^2. The particles passing through the charge detectors in the direction toward the ionization calorimeter generate a pulse $\sim$ 10 times greater than the particles moving in the opposite direction. Therefore, the charge detectors DD_1 and DD_2 are simultaneously also detectors of the direction of motion of the registered particles.

3. Graphite and Polyethylene Targets were used for measuring the effective cross sections of the inelastic interaction between protons and nuclei of carbon and hydrogen which are installed behind the charge detector DD_1. During the flight they periodically replaced one another; part of the time ($\sim 1/3$) the measurements were made without targets, placed outside the cross section /1820

of the ionization calorimeter. Registration and comparison of the proton flux of a given energy, penetrating the targets without interaction with the proton flux registered in the absence of targets, permits determining the effective inelastic interaction cross section between the protons and the nuclei of the targets.

4. Detectors of the Particle Interaction. As the interaction detectors, we used proportional counters which register the showers of secondary particles. One of the proportional counters (the PC_3) is placed under the target, another (the PC_4) under an additional lead layer, 2.5 cm thick, which serves for generating the electron-photon shower necessary for disintegration of the neutral pi-mesons generated in the interaction.

5. Four Thin Graphite Layers, 2.26 $g \cdot cm^{-2}$ each with proportional counters PC_7 - PC_{10} behind each layer, are designed for the registration of nuclear interactions of the primary particles entering the instrument from the side of the charge detector DN_2.

6. Auxiliary Radiation Detectors. The passage of a primary particle through the ionization calorimeter may be accompanied by the appearance of secondary particles scattered in the reverse direction. These latter, by entering the respective detectors, may distort the form of the proton spectrum. To study such phenomena, to evaluate their probability and to explain their roles in the measurements, shower indicators are placed in the upper part of the IC-15 on the side of the DD_1; for this we used four scintillation counters, included in the composition of the DD_1 and connected in pairs in the circuit of double coincidence C_iC_j. The coincidence of pulses C_i, simultaneously entering from several counters at the moment of passage of the registered particle through the DD_1 and the ionization calorimeter, indicate the passage through the detector of several shower particles. To determine their number we use the PC_2 counters (for operation of the DD_1) and the PC_{11} (for operation of the DD_2).

The auxiliary proportional counters PC_5 and PC_6, installed in the central part of the ionization calorimeter, participate along with the other detectors in the selection of those primary particles which pass through one of the charge detectors DD and the ionization calorimeter. The counters are adjusted in such a way that their output threshold devices operate only with passage through the counter of more than ten shower particles.

II. Operating Principles of the IC-15

Two possible types of operation are possible for the instrument in a flux of cosmic radiation: (a) the total registration of particles from all directions; (b) discrimination of particles in a relatively narrow solid angle in the direction passing through all the radiation detectors.

Registration of particles in the total flux is accomplished only with the aid of the ionization calorimeter, which in this case permits carrying out the total measurements of the energy spectrum of all the particles without discriminationg the charge. Due to the large mean effective area of registration and the large solid angle of the "scanning" (the geometric factor of the instrument in this case is equal to $1.4 \cdot 10^5$ $cm^2 \cdot ster$), these measurements /1821 possess a maximal energy range greater than 10^{15} eV.

Registration in the discriminated direction is accomplished in the small solid angle which is given by the charge detector, on the one hand, and the proportional counters at the output of the ionization calorimeter, on the other hand. The discrimination of particles in this solid angle is done by selecting electric signal coincidences from one of the charge detectors (DD_1 or DD_2) with signals from the proportional counters PC_3 or PC_7 - PC_{11}.

Let us look at the registration of a particle entering the instrument from the side of the charge detector DD_1. It successively intersects the DD_1, the monitor counter PC_2, the targets (if they are included) and, along with the products of the interaction (if they take place), enter the interaction

detector PC_3, PC_4. In five of the first filter layers of lead (2.5 cm each) an intense development of an electron-photon showers takes place which is necessary for the disintegration of the neutral pi-mesons generated in the interaction. The energy transmitted by these particles may be determined from the amount of ionization in the IC_1 - IC_4 ionization chambers.

Further interactions and transformations of the particles take place in subsequent layers of the iron filter. Measurement of the ionization, created by the particles of the shower, is done with the ionization chambers IC_5 - IC_{16}. The presence of iron and lead layers and individual ionization detectors permits, in principle, measuring the cross sections of the particle interaction for heavy nuclei.

Along with the combined operation of the charge detectors and energy in the IC-15, an autonomous registration of the particles by the DD_1 and DD_2 charge detectors outside the connection with the ionization calorimeter takes place, thus permitting a determination to be made of the charge spectrum of the particles in the energy range $\sim 10^9$ - 10^{10} eV/nucleon.

Below we give a slightly more detailed description of certain structural characteristics and parameters of the basic functional modes of the IC-15.

III. Structural Characteristics of the IC-15 Ionization Calorimeter Filter

The maximal thickness of the IC-15 filter in the direction determined by the charge detectors (Figure 1) is 855 $g \cdot cm^{-2}$ of iron and 140 $g \cdot cm^{-2}$ of lead, or a range of 7.5 for the nuclear interaction. In such an amount of matter, about 90% of the energy from the primary particle is absorbed on the average. The mean thickness of the filter for total registration of particles is about 400 $g \cdot cm^{-2}$, which is much greater than the three ranges for the nuclear interaction. For structural reasons the layers of iron were made of various thickness from 4.8 to 9.8 cm (in the middle part of the calorimeter, because of the necessity of installing additional counters of the telescopic device PC_5, PC_6

the layers of the filter were taken less than the thickness). The overall structure of the filter is shown on Figure 2.

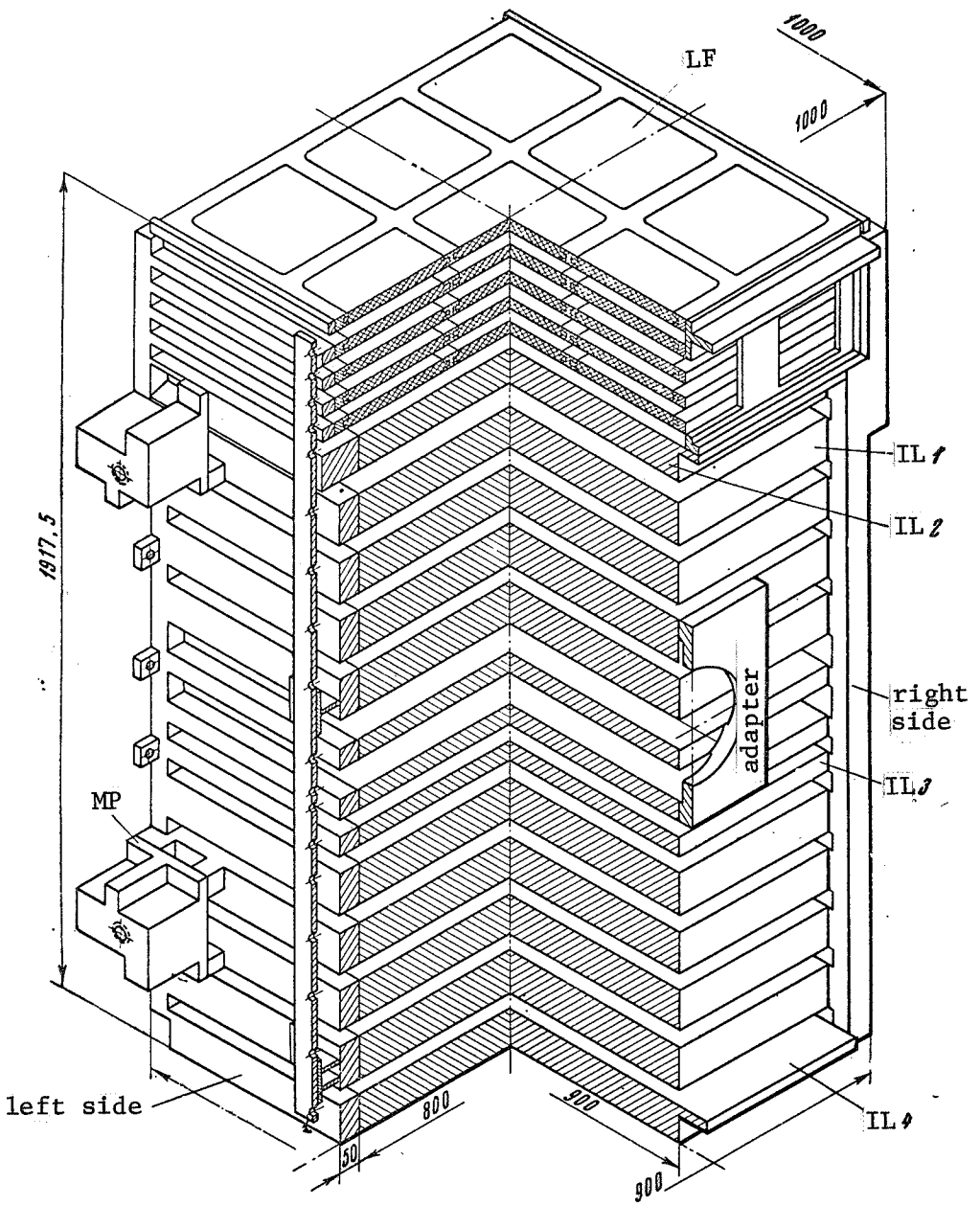

Figure 2. Filter layers of the ionization calorimeter; LF is the lead filter. MP are the mounting points of the instruments: IL are the layers of iron.

Ionization Chambers and Proportional Counters

An ionization chamber of welded construction was made of stainless steel, 1.5 mm thick, in the form of a parallelipiped with outer dimensions 900 x 1045 x 33.8 mm. The chamber was divided by rigid partitions into 15 sections completely filled with gas (size of the section was 30 x 60 x 945 mm). Along the section were stretched steel threads (1 mm in diameter) which carry out the function of the inner electrode and have a common electric outlet. /1822

The ionization chambers are filled with xenon (instead of the argon which is used ordinarily) with an admixture of 5% nitrogen up to a total pressure of 790 mm Hg. Use of a gas with a high density permits increasing the ionization effect generated in the chamber by fast charged particles. The working voltage on the chamber is 1750 V and guarantees a sufficiently rapid (during the course of several microseconds) collection of the part of the charge to be registered, formed in the gas of the chamber by the ionizing particle.

The proportional counters PC_8 - PC_{10} have an analogous construction. /1823 These counters with an effective area of 1.25 m^2 possess 17 sections with diagonal measurements of 30 x 60 mm. The dimensions of the counters correspond to the dimensions of the sectional filters, between which they are placed as the interaction detectors. The counters PC_4 - PC_7, located under the filter layers of the calorimeter, have 15 sections of the same size. The proportional counters PC_2, PC_3, PC_{11} are two-layered with the height of the gas space in each layer equal to 50 mm. The inner electrodes of the counters are made of tungsten thread, 0.1 mm in diameter. The counters are filled with argon with a 10% admixture of methane up to a total pressure of 270 - 300 mm Hg; the effective voltage on the counters is 1.6 - 1.7 kV. Passage of a fast singly charged particle through the counter in a direction perpendicular to its plane generates at its output a voltage surge with the more probable amplitude of $\sim$1 mV.

Ionization Detector Units and Measuring the Ionization Impulses

The ionization chambers and the proportional counters are equipped with an individual high-voltage source and pulse amplifiers with a coefficient of amplification of ~ 300 for the chambers and ~ 600 for the counters. Two additional amplitude discriminators in the electron circuits of the proportional counters serve for selecting the "window", corresponding to the ionization effect of the individual singly charged particle.

Figure 3 shows the amplitude spectrum of the impulses, registered by the upper half of the proportional counter PC_3 from the mu-mesons at sea level. Along the abscissa are plotted the numbers of the channels of the amplitude analyzer AI-100-1, and the values of the thresholds are shown for the discriminators which select the "window" for registering the singly charged particle. Along the ordinate is the number of impulses registered in the given channel. The PC_4 assembly is similarly adjusted. For such an adjustment the effectiveness of registration of an individual singly charged particle in the range of the "window" is 75% and the probability of registration of two particles as one is less than 20%.

Reliable registration of the impulses in the ionization chambers begins from the ionization effect, created by the simultaneous passage of 40 - 50 fast, singly charged particles. From the output of the amplifiers the impulses from the ionization chambers and the proportional counters are directed to a multi-channel amplitude-measuring device. Each output channel of the ionization detector (with the exception of the PC_5 and PC_6 counters, which serve only for generating the control signals) is equipped with an individual amplitude analyzer with logarithmic characteristics and a dynamic range of ~ 500. Several channels are equipped with two amplitude analyzers for increasing the dynamic range of the measured amplitudes (the PC_4, PC_7, PC_{10}, DD_1 and DD_2 are such channels of proportional counters).

The amplitude analyzer unit carries out a double analog-digital conversion of the amplitude of the registered impulse into a code and transmits it to the telemetry system. Furthermore, its function includes the time selection (with a resolving time of 3 - 6 microseconds) of the registered impulses; amplitude analysis of the input impulse and storage of the code representing it with transmission to the telemetry equipment is accomplished only in the presence of a command in the form of a controlling impulse, generated by the logic unit of the IC-15 (see below).

All together in the amplitude-measuring equipment of the IC-15 there are 42 amplitude analyzers for measuring the amplitude of the impulses entering from the proportional counters, the ionization chambers and the Cerenkov counters in the charge detectors. /1824

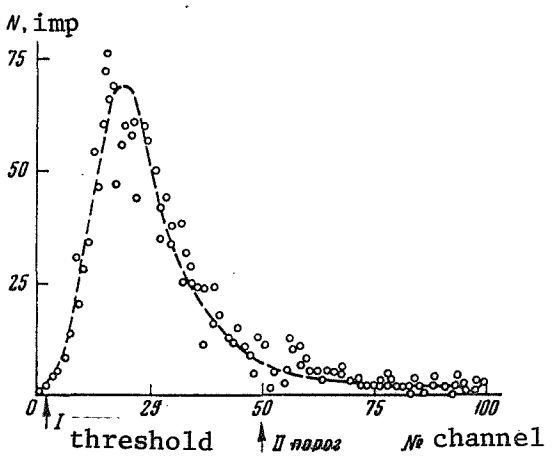

Figure 3. Amplitude spectrum of pulses, registered by the upper half of the PC_3 proportional counter from mu-Mesons at sea level.

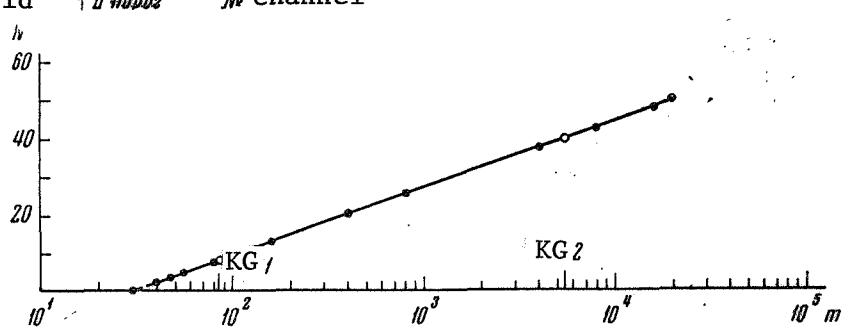

Figure 4. Calibartion characteristics of the circuit of registration of the amplitudes of pulses from the ionization chamber.

Figure 4 shows the amplitude-numerical calibration of the characteristics of one of the impulse registration channels from the ionization chamber. The

amplitude of the calibrated voltage impulses at the amplitude input is expressed here in the number of the relativistic singly charged particles, producing an equivalent ionization (abscissa) in the gas of the chamber. Along the ordinate are plotted the respective values N of the numerical code used by the amplitude analyzer. From the graph it is clear that the measurements may be made here for the ionization effects, created simultaneiously by the passage of from 40 - 50 to $2 \cdot 10^4$ particles.

To check the change in sensitivity of the amplifier circuits and the measuring devices during the experiment we designed calibration generators which were turned on by command from Earth. The calibrated voltage impulses are transmitted to the input of each amplifier in the circuits of the ionization chambers and proportional counters. The values of these control amplitudes (KG1 and KG2) are shown on the amplitude curve (Figure 4).

Charge Detectors

Measurement of the particle charge in the detector DD is based on the registration of Cerenkov radiation, the intensity of which is, as we know, a quadratic function of the charge of the moving particle. The detector with /1825
a large area DD is composed of a larger number of Cerenkov counters than was used in previous experiments. The counters form the next "graduated" structure of the instrument; four Cerenkov counters are connected to the section, representing the autonomous instrument; four sections, operating for the total measuring output, comprise the detector DD.

Figure 5 shows a schematic cross section of one section with the respective geometric dimensions indicated. The section is composed of four Cerenkov counters, connected with two general scintillation counters of the "telescopic" device. Coincidence of the impulses entering from both counters, at the moment of passage of the particles, serves as the signal for selection of impulses at the connected output of the Cernekov counters of the section. The geometric factor of the charge detector is equal to 1960 $cm^2 \cdot ster$, which exceeds the

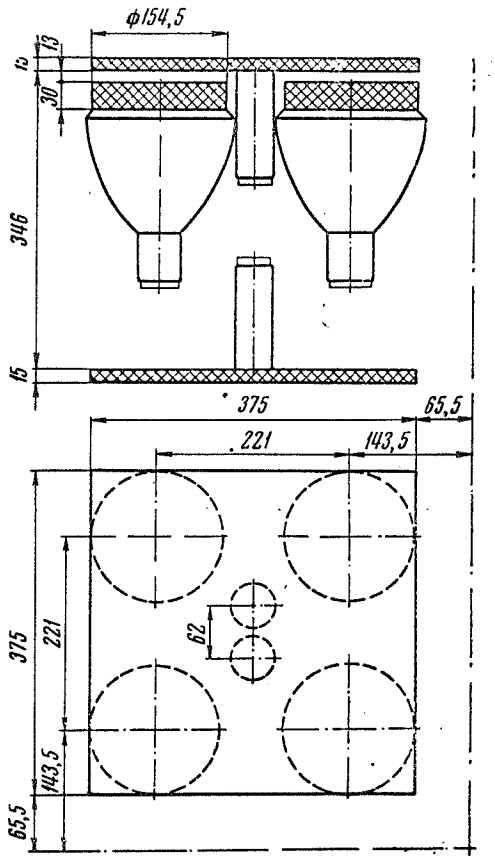

Figure 5. Schematic cross section of one section of the charge detector DD.

relative aperture of the charge detector used in [6] by 18 times.

The photomultipliers of the detector DD are designed for periodic automatic sensitivity control. Twice a day, on command from the Earth, the four generators of reference light impulses are turned on (each section is served by an individual light generator). The light impulses are directed with the aid of pliable light conductors on the photocathodes of the PM of the Cerenkov counters and permit automatic sensitivity control of the photomultipliers relative to one another by the comparison circuit and mechanism of regulating the voltage.

Figure 6, b shows the form of the amplitude spectrum registered from /1826 the mu-mesons at sea level with the combined operation of the four Cerenkov counters of one section, when the sensitivity control of the PM-49 is done automatically. Prior to automatic control the amplitude spectra from these same counters had the shape shown on Figure 6, a.

Targets

Each of the "thick" targets (graphite and polyethylene), located under the charge detector DD_1, is structurally made of two halves, placed on opposite sides (Figure 1). Interchange of filters is done by the successive shift of the halves toward the operating window of the device or beyond it.

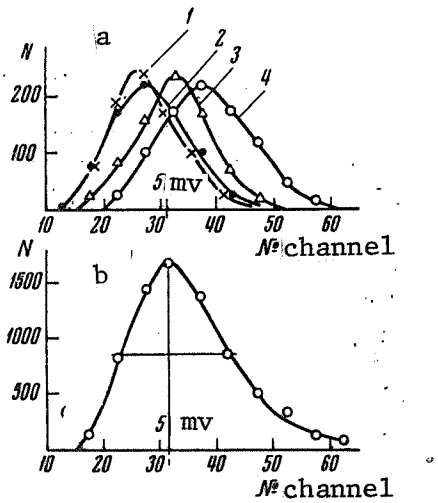

Figure 6. a — Spectra of the pulse amplitudes from the mu-mesons for four Cerenkov counters of one section prior to control (1 - PM-49, No. 14; 2 - PM-49, No. 16; 3 - PM-49, No. 13; 4 - PM-49, No. 15); b — shape of their overall spectrum after automatic sensitivity control.

The overall thickness of the carbon target is 22.3 $g \cdot cm^{-2}$; that of the polyethylene target is 26 $g \cdot cm^{-2}$. Interchange of the carbon and polyethylene targets is done twice a day on command from the Earth.

Interaction Detector

Based on the ionization effect produced in it, the two layer proportional counter PC_3, located under the thick target, permits distinguishing the case of passage of an individual singly charged particle (proton) without interaction in the target from the cases of inelastic interaction with the formation in the target of a shower of secondary charged particles.

If there are no charged particles in the nuclear interaction, but only mu^0-mesons, then such an interaction may be registered from the ionization effect in the proportional counter PC_4 as a result of the development of an electron-photon shower in the lead filter over this counter. Therefore, the indication that there is no interaction in the target is the presence of impulses from the PC_3 and PC_4 counters with amplitudes in the range of the "window". The IC-15 electron device especially distinguishes such cases and produces a special signal N_1 from the impulses of the PC_3 and PC_4, thus indicating a lack of interaction in the target with passage of the individual singly charged particle.

Principles of the Measurements and Electron Registering Device

The basis of registering particles in the IC-15 spectrometer comprises two methods of making measurements. The first consists of a selection of registering events of a rather narrow class (for example, protons with a given energy E) with the subsequent measurement of the time of onset of the distinguishable events. The second method includes individual amplitude measurements of the impulses from the detectors for each registered case. The first method is used for registering specific events, the second for rather rare events, for which individual telemetric measurements can be made.

Included in the first of these is the registration of the total flux of high-energy particles. In these measurements only the ionization calorimeter is used. The impulses from all the ionization chambers are summed by amplitude in the total circuit, at the output of which an amplitude discrimination is made for 10 levels E_i ($i = 1 - 10$), approximately equidistant in the logarithmic scale. Measurement of the registration times by channels of these discriminators permits determining the intensity of the particles, the energies and the shape of the energy spectrum in the range from $10^{11} - 10^{16}$ eV.

Measurements of this same type are associated with discrimination of /1827
the proton component of cosmic radiation. Based on the signals Z_1 which enter from the charge detector DD_1, the protons are discriminated that do not undergo interaction in the target (N_1) and which pass in the range of the solid angle of the calorimeter with an energy release $\geq E_i$. The required choice of particles is done by coincidence of the signals Z_1, N_1, E_i. Registration of the event along the channels selected by coincidence of Z_1, N_1, E_i permits determining the energy spectrum of the protons and making the measurement of the effective cross section of their interaction in the nuclei of carbon and hydrogen by comparing the registered flux in the presence of targets and with out them. Included in this same type of measurements is the discrimination of particles by charges Z_i in the detectors DD_1, DD_2 with subsequent autonomous

registration of the events C_2Z_i selected by coincidence of the impulses C_2 from the scintillation counters DD with the signals Z_i of the amplitude impulse discriminators at the output of the Cerenkov counters.

Six threshold devices have been designed, tuned to levels corresponding to the passage of particles with charges $Z_2 \geq 2$, $Z_3 \geq 6$, $Z_4 \geq 10$, $Z_5 \geq 20$, $Z_6 \geq 30$, $Z_7 \geq 50$, and one general threshold device, the operation of which is associated with the passage of any charged particle $Z_0 \geq 1$. Individual measurements in the total flux are made only with respect to the total energy release in the calorimeter for rather rare particles with an energy of $E \gtrsim 5 \cdot 10^{13}$ eV. With such an energy release an amplitude analysis is made for the signals corresponding to the total energy release in the ionization calorimeter. The amplitude analyzer, designed for these circuits, has an amplitude range greater than 10^3.

For particles entering in the range of the limited solid angle, the individual registration is done with an amplitude analysis of all the detectors DD, PC, IC (with the exception of the PC_5, PC_6), beginning from an energy of the particles $E_0 \gtrsim 5 \cdot 10^{12}$ eV. Here the command M is given which resolves the registration and the amplitude analysis of the impulses from all the detectors. From this same command, in a special analyzer, measurement of the total energy release in the calorimeter is also given and the presence of signals from the shower indicators DD_1 are noted, i.e., registration of the coincidence impulses MC_iC_j is done, where C_iC_j are the signals from the respective pair of scintillators DD_1 ($i, j = 1 - 4$).

For individual registration of the particles in the range of lower energies a selective registration is made of events with an energy release of $E \gtrsim 4 \cdot 10^{11}$ eV by the scaling down of pulses of these events in a ratio of $\sim 1{:}43$. For the events thus selected a special command MB is given, which resolves the amplitude measurements along the channels of all the detectors. Development of all these signals of control and registration is done in the assemblies of the electron registering device IC-15 which numbers 21 units.

On command transmitted from the Earth, it is possible to turn on both detectors DD_1 and DD_2 or the operation of one of them with the ionization calorimeter. It is also possible to turn off the detectors and the ionization calorimeter operates independently by registering the energy spectrum of particles in the total flux. Using special commands, the SEZ-12 and SEX-13 instruments are turned on and off. Control of the operation of the complex of scientific equipment is done both from the program equipment located on board the stations and from command on Earth.

A number of institutes and design organizations of the Academy of Sciences USSR and Moscow State University participated in the development of individual units and the manufacture of the scientific equipment, and the authors wish to express their appreciation to them.

REFERENCES

1. Grigorov, N. L., V. E. Nesterov, I. D. Rapoport, I. A. Savenko and G. A. Skuridin. Reports from the Ninth International Conference on Cosmic Rays, London, September 1965. Preprint from Moscow State University Press and the Press of the Academy of Sciences, USSR, Moscow, 1965. /1828

2. Grigorov, N. L., V. E. Nesterov, I. D. Rapoport, I. S. Savenko and G. A. Skuridin. Reports from the International Astronautics Congress, Afina, 1965. Preprint from Moscow State University Press and the Press of the Academy of Sciences USSR, Moscow, 1965.

3. Grigorov, N. L., G. P. Kakhidze, V. Ye. Nesterov, I. D. Rapoport, I. A. Savenko, A. V. Smirnov, A. F. Titenkov and P. P. Shishkov. Kosmicheskiye issledovaniya, Vol. 5, No. 3, 1967, p. 383.

4. Grigorov, N. L., S. I. Voropayev, L. F. Kalinkin, V. A. Labutin and I. A. Savenko. Sb. Kosmicheskiye luchi (Collection: Cosmic Rays), Nauka Press (in press), No. 13.

5. Grigorov, N. L., G. P. Kakhidze, I. D. Rapoport and I. A. Savenko. Sb. Kosmicheskiye luchi (Collection: Cosmic Rays), Nauka Press (in press), No. 13.

6. Volodichev, N. N., N. D. Grigorov, Yu. V. Mineyev, O. B. Kislyakov, V. Ye. Nesterov, I. D. Rapoport, I. A. Savenko, A. V. Smirnov and Ye. M. Yakovlev. Kosmicheskiye issledovaniya, No. 5, 1967, p. 119.

7. Grigorov, N. L., L. F. Kalinkin, V. Ye. Nesterov, Ye. A. Pryakhin, I. A. Savenko, Ye. A. Sysoyev and I. V. Estulin. Kosmicheskiye issledovaniya, No. 5, 1967, p. 124.

8. Grigorov, N. L., V. Ye. Nesterov, I. D. Rapoport, I. A. Savenko, G. A. Skuridin and A. F. Titenkov. Kosmicheskiye issledovaniya, No. 5, 1967, p. 395.

9. Grigorov, N. L., V. E. Nesterov, I. D. Rapoport, I. A. Savenko and G. A. Skuridin. Reports on the Tenth International Conference on Cosmic Rays, Canada, June, 1967. Preprint from the All-Union Institute of Scientific and Technical Information, Moscow, 1967.

10. Grigorov, N. L., V. Ye. Nesterov, I. D. Rapoport, I. A. Savenko, G. A. Skuridin and A. F. Titenkov. Izv. An SSSR, Ser. fiz., No. 31, 1967, p. 1222.

11. Volodichev, N. N., N. L. Grigorov, V. Ye. Nesterov, I. D. Rapoport, I. A. Savenko, G. A. Skuridin and A. F. Titenkov. Reports on the All-Union Conference on Cosmic Rays, Alma-Ata, October, 1966. Preprint from the Press of the Academy of Sciences USSR and Moscow State State University Press, Moscow, 1966.

12. Akimov, V. V., N. L. Grigorov, V. Ye. Nesterov, I. D. Rapoport, I. A. Savenko, G. A. Skuridin and A. F. Titenkov. Sb. Kosmicheskiye luchi (Collection: Cosmic Rays), No. 13 (in press).

13. Grigorov, N. L., V. Ye. Nesterov, I. D. Rapoport, I. A. Savenko and A. F. Titenkov; Reports of the All-Union Conference on the Physics of Cosmic Rays in Tashkent, 1968, Part II, No. 1, p. 1, Physics Institute im. P. N. Lebedev, Moscow, 1969.

14. Grigorov, N. L., V. E. Nesterov, I. D. Rapoport, I. A. Savenko and G. A. Skuridin. Reports on the Eleventh International Conference on Cosmic Rays, Budapest, August 1969. Preprint, 69, Scientific Research Institute of Nuclear Physics, Moscow State Univeristy, Moscow, 1969.

15. Vasilova, R. N., N. L. Grigorov, G. P. Kakhidze, O. M. Kovrizhnykh, V. Ye. Nesterov, I. D. Rapoport, I. A. Savenko, G. A. Skuridin and A. F. Titenkov. Izv AN SSSR, Ser. Fiz., No. 30, 1966, p. 1610.

16. Grigorov, N. L., V. Ye. Nesterov, I. D. Rapoport, I. A. Savenko and G. A. Skuridin. Izv. AN SSSR, Ser. Fiz., No. 31, 1967, p. 1450.

17. Grigorov, N. L., V. Ye. Nesterov, I. D. Rapoport, I. A. Savenko and G. A. Skuridin. Kosmicheskiye issledovaniya, No. 5, 1967, p. 420.

18. Akimov, V. V., N. L. Grigorov, V. Ye. Nesterov, I. D. Rapoport, I. A. Savenko and G. A. Skuridin. Sb. Kosmicheskiye luchi (Collection: Cosmic Rays), No. 13, (in press).

19. Akimov, V. V., N. L. Grigorov, V. Ye. Nesterov, I. D. Rapoport and I. A. Savenko. Reports of the All-Union Conference on the Physics of Cosmic Rays in Tashkent, 1968; Part I, No. 1, p. 98, Physics Institute im P. N. Lebedev of the Academy of Sciences, MOscow, 1969.

20. Grigorov, N. L,, V. E. Nesterov, I. D. Rapoport, I. A. Savenko and G. A. Skuridin. Reports on the Eleventh International Conference on Cosmic Rays. Budapest, August, 1969. Preprint 167, Scientific Research Institute of Nuclear Physics, Moscow State University, Moscow, 1969.

21. Grigorov, N. L., Yu. S. Klintsov, V. Ye. Nesterov, I. D. Rapoport, I. A. Savenko and B. M. Yakovlev. Izv. AN SSSR, Ser. fiz., No. 30, 1966, p. 1773.

22. Grigorov, N. L., G. P. Kakhidze, I. D. Rapoport and I. A. Savenko. Reports of the All-Union Conference on the Physics of Cosmic Rays in Tashkent, 1968; Part II, No. 1, p. 19, Physics Institute im. P. N. Lebedev of the Academy of Sciences, USSR, Moscow, 1969.

Translated for National Aeronautics and Space Administration under Contract No. NASw-2035, by SCITRAN, P.O. Box 5456, Canta Barbara, California 93103